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A SNOW INDEX USING 200MB WARM ADVECTION

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ABSTRACT

Warm advection at 200mb is used to forecast the amount of snowfall in the ensuing 24 hours. The type of advection at 700mb is used to modify the forecast. A test of the method was made from October 15, 1976 through March 1, 1977 with favorable results.

INTRODUCTION

Most heavy snow forecast techniques suffer from being too complicated, are too time-consuming, or fail to provide a forecast of both maximum amount and area. The method presented here overcomes some of these difficulties. An initial estimate (or "snow index") is made from a calculation using the 200mb chart. Adjustments are made based on advection at 700mb and a few simple guidelines. Application of the technique requires only a few minutes.

BACKGROUND

Most snow forecasting schemes use the location of low pressure centers (surface or aloft), or vorticity maxima. See Goree and Younkin (1966), Spar et al. (1970), Hanks (1967), and Harms (1973). Ostby (1974) suggested the use of Model Output Statistics (MOS). Goree and Younkin identify prediction of heavy snow as one of the most important functions of the National Weather Service, but state that "...on the average, only a modest degree of success can be claimed."

Most of these approaches make no attempt at forecasting the amount of snowfall. Harms and Hanks make such an effort but if the area of concern is not on the forecast path of maximum snowfall, then the amount is only an estimate based on the location in relation to the maximum. All except Ostby relate heavy snowfall to the track of the surface cyclone or its upper features.

TYPE OF PRECIPITATION

The type of precipitation must be determined before snowfall amounts are to be successfully forecast. The operational POF forecasts based on MOS incorporated the better features of Wagner (1957) and Younkin (1967). The MOS POF progs are quite good, and if they forecast snow any precipitation is likely to be snow. However, a few important snowfalls have occurred when the POF was less than 50%. Cooling caused by precipitation is apparently not entirely accounted for in the POF progs. Wexler, et al. (1954)

shows that with a moist adiabatic lapse rate, surface air at a temperature of 40°F can be cooled to 32°F by .38 inch of precipitation. Evaporation can modify the lower atmosphere in a short time. The wet-bulb temperature curve from soundings may be used to determine the type of precipitation. A simple rule is that precipitation will be snow or change to snow whenever the wet-bulb temperature curve goes below freezing within 2500 feet of the surface and does not go above freezing at a higher level. Significant precipitation should be expected (about .25 inch, water equivalent).

In January 1974, the type of precipitation was compared to the height of the 200mb surface over the contiguous 48 states. Snow accounted for 81% of the precipitation area between the 164 (Note: Contour values in decameters with initial "1" omitted - e.g., 164 = 11640 meters) and 176 contours at 200mb. The area was determined by one degree latitude - longitude "squares", where any report of precipitation within a square was assumed to be valid for the entire square. Rain occurred in 11% and freezing rain in 8% of the area. Between the 176 and 188 contours snow accounted for 36% of the area, rain 51%, freezing rain 12%, and ice pellets 1%. Experience gained since 1974 suggests the 176 contour as the 50% probability line for low elevations with average surface pressures (1005 to 1015mb). For each 3000 ft increase in elevation or for higher surface pressures the next higher contour (188) is used. Also for lower pressures or in the immediate coastal sections the 50% probability is one contour lower (164).

DEVELOPMENT OF TECHNIQUE

It should be emphasized that these comments are only for wintertime conditions (mid-October through February). This technique relies primarily on the 200mb chart with minor checks from the 700mb and surface charts. First a brief word about the 200mb chart. Warm air normally occurs in 200mb troughs and cold air in the ridges. Temperatures are -40°C to -45°C in strong troughs and are -65°C or colder in strong ridges. Temperatures remain in the -50s with weaker systems. Thus the thermal pattern at 200mb reflects the strength of the system occurring at lower levels.

The indicated advection pattern at 200mb gives important clues to the vertical motion fields and, more importantly, it indicates the potential vertical motion field. Austin (1951) says, "The strong (temperature) changes which occur in the upper atmosphere may be considered as arising from vertical motion fields which accompany the sea-level pressure changes and which arise from such low-level processes as heating or cooling. A non-uniform field of vertical motion creates strong advective fields in the lower stratosphere as a result of the abrupt change in the vertical temperature gradient near the tropopause."

The thermal field at 200mb can then be a measure of the potential vertical motion over a particular location. For example, if the 200mb temperature at some location is -53°C and the warmest 200mb temperature upstream is -48°C, then the potential warming at 200mb as a result of the upstream system is only 5C° and the vertical motion as it approaches will be only moderate. On the other hand, if the 200mb temperature at some location is -60°C and the warmest temperature upstream is -45°C, then the potential warming at 200mb is 15C° and the vertical motion will be strong, provided the change occurs in a reasonably short time. Experience has shown a reasonable advective speed for the warm pocket to be about 14 degrees at latitude (°lat) in 24 hours, or an average of 35 knots. Examination of the 200mb charts over several winter seasons reveals some interesting relations:

1. Cloudiness and precipitation tend to increase under indicated warm advection and decrease under indicated cold advection at 200mb.

2. The heaviest snowfall in the ensuing 24 hours occurs near the coldest air at 200mb that is downstream from the warm pocket, provided of course that the column of air is cold enough for snow. This is usually immediately downstream from the strongest indicated warm advection at the initial time (T+0).

3. Vorticity maxima at 500mb tend to move toward the 200mb cold pockets; e.g., if a 200mb cold pocket develops northeast of a 500mb low, the low will recurve in 24 hours. Note that the 200mb warm pocket almost always coincides with the 500mb vorticity maximum, particularly in well-developed systems. Generally the direction of movement of a vorticity maximum at T+12 to T+36 hrs will be parallel to a line connecting the 200mb warm and cold pockets at T+0. On occasions when the 200mb warm pocket is ill-defined or shows as an elongated warm sector, then the 500mb vorticity maximum is used as the 200mb warm pocket. Forecast continued digging if the cold pocket is southeast of the 500mb low and recurvature if the cold pocket is northeast of the 500mb low. This technique should not be used with two types of patterns. They are: (1) large scale cyclonic flow over North America with short waves moving rapidly through, and (2) cutoff lows in the southwestern U.S. that have remained nearly stationary for the previous 24 hours.

The storm that caused blizzard conditions through Eastern Colorado and Northwestern Kansas in March of 1977 is traced in Figures 1a and 1b. The crosses connected with the dashed lines depict the 500mb vorticity maxima. On Figure 1a points marked "B" indicate the 36-hour forecast barotropic vorticity maxima, while points marked "L" indicate the positions of the 36-hour LFM vorticity maxima. Dotted lines connect each "B" and "L" to the cross corresponding to the verifying time. On Figure 1b the solid arrows connect the 500mb vorticity maxima with the coldest 200mb air downstream. The head of the arrow marks the central point of the coldest 200mb temperature. Note the rotation of the arrow heads with time.

At 00GMT March 11 the LFM forecast a closed low over Northeast New Mexico - an excellent forecast, while the barotropic did rather poorly. In the next three forecast periods the LFM center was too far south while the barotropic center was equally too far north. Following these periods both types of progs improved. The LFM is known to be better than the barotropic in the development stages but is slow in forecasting recurvature.

The 200mb temperature pattern seems to give clues about 24 hours in advance of the recurvature. Note the solid arrow drawn from the 12GMT 200mb chart on the 9th indicated a continued digging through 36 hours. But by 00GMT on the 10th, the solid arrow had turned nearly east-west reaching from Oregon to West Virginia. This suggested the 500mb low would begin to turn eastward in about 24 hours. By 12GMT on the 10th the solid arrow, Utah to Pennsylvania, suggested a northeastward movement after 24 hours. Note that the track of the 500mb low was essentially as suggested by the solid arrows.

4. Cold air (-60°C or colder) usually develops northwest of a short wave trough before it deepens. The cold air is frequently over the Gulf of Alaska as the short wave moves on the west coast.

5. The height contours at 200mb are fairly conservative. Extrapolation of the past 24-hour changes for the next 24 hours usually works well. Generally the contours may be used in situ or with only a small forecast change, usually less than 120 meters (one contour interval).

Jacobson (1956) used the coldest temperature at 500mb and the wind flow to forecast surface development. Warm air at 200mb reflects cold air at 500mb. If the storm is not strong enough to affect the 200mb temperature, heavy snow usually does not occur. Jacobson said it was not necessary to worry about the moisture in the developing storms. If the dynamics are strong, the moisture will find its way into the storm. This appears to be true. Initially dry conditions serve only to delay precipitation a few hours.

Oliver and Oliver (1945) and many others concur that cold advection in the mid-troposphere (700mb) indicates downward motion and warm advection upward motion. The 700mb advection is used to adjust the forecast derived from the 200mb chart.

THE INDEX

1. The index, or the average snowfall, in inches, for the following 24 hours will be approximately one-half the indicated warm advection (C degrees) at 200mb provided the column of air is cold enough for snow. The maximum indicated warm advection, limited to 840nmi (or 15°lat) upstream should be used for a 24-hour forecast. If the indicated warm advection extends less than 6°lat (360nmi) upstream from the forecast area, the precipitation is usually of short duration. Generally the indicated warm advection is measured from the warmest temperature to the coldest temperature along the 200mb contours.

2. If cold advection is observed within 8°lat of the forecast area at 700mb, the snowfall forecast in paragraph 1 should be divided by 2. The index then becomes 1/4 the indicated warm advection at 200mb. The 700mb temperature 8°lat upstream should be compared with the 700mb temperature over the forecast area. If the upstream temperature is colder than the forecast area temperature, then cold advection is assumed and the 1/4 rule is used; otherwise the 1/2 rule is used.

3. Maximum snowfall in the ensuing 24 hours occurs near the coldest 200mb temperature that is downstream (parallel to contours) from the warmest 200mb temperature. It will frequently be within or near the area outlined by Ostby. Heavy snow bands are almost always parallel to the T+0 200mb contours or cross them at a slight angle from higher to lower values as the snow progresses, usually northeastward. This is the normal turning of the 200mb contour pattern as the storm moves northeastward.

4. Local effects (e.g., the Great Lakes, hills and mountains) can affect the amount of snowfall considerably.

5. Location of the area of heavy snow is usually the main problem. As noted previously the heaviest snow is almost always immediately downstream from the maximum indicated warm advection on the 200mb chart. The width of the heavy snow band is frequently about the same as the distance between adjacent contours on the 200mb chart. The southwest end of the heavy snow band should be placed just downstream from the maximum indicated warm advection. The northeastern end of the forecast area should be near the eastern side of the area of coldest 200mb temperature, or limited to 14°lat downstream from the warmest 200mb air for a 24-hour forecast (21°lat for a 36-hour forecast).

The snowfall of December 6-7, 1976 is presented as an example of an average snowfall event (Figure 2). It was selected because a forecast was made shortly after receiving the 200mb chart for 00GMT December 6, 1976. The dotted line outlines a forecast area for an average of 2-1/2 inches of snowfall to verify at 12GMT December 7, 1976. Warm advection was indicated at 700mb using the criteria described earlier. Five degrees warm advection was indicated at 200mb from Colorado to the forecast area giving a snow index of 2-1/2. The area was selected as being in a cold 200mb temperature zone which was downstream from the warmest 200mb temperature. It was selected in an area where the POF was 50 percent or higher for three subsequent 12-hour forecast periods. The western end of the area was placed slightly downstream from the significant warm advection and the eastern end was placed far enough to cover most of the cold 200mb temperature. Twenty-one latitude degrees downstream from the warm pocket allows for a 35 knot average movement through the 36-hour forecast period. The width of the forecast area was selected as 120 meters on the 200mb chart.

The observed 24-hour snowfall area at 12GMT December 7, 1976 is shown by the dash-dot line. It includes all reports of more than one inch. The average in the area was 2-1/2 inches, with a maximum of 4 inches. This forecast was considerably better than average and took less than 5 minutes to prepare. The surface chart for 00GMT December 6, 1976 is shown in Figure 3. Twenty-four hours later the occluded front extended from a weak low north of the Great Lakes through lower Michigan to another weak low in southern Louisiana.

TEST OF TECHNIQUE

The snow cover as indicated on NAFAX map N73 was used to determine the amount of snowfall for each day from October 15, 1976 to March 1, 1977 by subtracting the snow depth for the previous day from that for "today" over the 48 states and adjacent areas of southern Canada. The liquid precipitation indicated on NAFAX N81 was also used to "confirm" the snowfall. This method has obvious weaknesses, notably the assumption that each snowfall began after 12GMT and ended by 12GMT the next day. Settling and melting are not accounted for and surely some large amounts are omitted from the snow cover chart. Nevertheless, the size of the sample and the cross checking with the liquid precipitation should have given a fair estimate of the average snowfall. Mountain top reports and isolated reports, as well as reports obviously influenced by the Great Lakes, were not used in this test. A minimum of three reports over an area of at least 3000 square miles was required for consideration as a snow event.

The highest index obtainable in the U. S. or adjacent section of Canada was derived from the 12GMT charts each day during the test period and compared to the snowfall reported 24 hours later. On 58 days no index was recorded due to a lack of significant 200mb warm advection; no significant snow was reported on the following days. All other indices and subsequent snowfall are listed in Table I and compared in Figure 4. The abscissa is the snow index (or forecast snowfall) and the ordinate is the observed average snowfall. The plotted numbers represent the maximum snowfall reported. A perfect forecast of the average snowfall would fall on the heavy line. The lighter lines above and below represent a departure of one inch. There were a few occasions where one or more of the charts were missing, and more than one snow event was recorded on a few charts. Of the 80 snow events, 64 percent were within one inch of the forecast amount.

Here are some known weaknesses of this technique:

1. Heavy snow should not be forecast beneath a strong confluent 200mb flow. The heavy snow will usually be south of the confluent zone.

2. Heavy snow should not be forecast south of the surface low. Occasionally the 200mb warm pocket and cold pocket will appear south of a well-developed surface low. Under these conditions little or no precipitation occurs, as the surface low usually moves rapidly eastward, parallel to the 200mb contours. This situation occurs most frequently with northwest flow aloft.

3. Under northwest flow aloft the systems can move rapidly and some snow may fall with indicated cold advection at 200mb. This was observed five times during the test period. Maximum snowfall for these events was two inches. Most stations reported 1 inch.

4. Occasionally a weak trough-ridge couplet at 200mb will accompany a 500mb low and signal a turn eastward too early. This pattern has very weak flow between the trough and ridge and the half-wave length is usually less than 10° lat.

5. This forecast scheme is known to be unreliable in spring and early fall. It should not be used before October 15 or after March 10. Late spring storms have been observed with little temperature advection at 200mb and others have occurred under the strongest 200mb warm advection rather than the coldest air, as used in winter.

A series of 200mb charts is presented (Figures 5 through 8) to illustrate the sequence of events in connection with heavy snow which fell over the northern portions of Texas and Louisiana in late January 1977, as delineated by the dash-dot line in Figure 7. Cold air had pushed southward with the surface cold front well into the Gulf of Mexico by 12GMT January 29, 1977. A 500mb closed low off the southern California coast was forecast to move eastward while opening into a trough by 12GMT January 31, 1977.

The 200mb chart for 12GMT January 29 (Figure 5) indicated the strongest warm advection over southern Arizona. Maximum precipitation was reported over southern Arizona at 12GMT January 30. A strong confluent zone was noted from the four corners to the Texas Panhandle. The coldest air was from southeastern New Mexico across North Texas, a potential threat zone for significant precipitation.

By 00GMT January 30 (Figure 6) temperatures warmer than -50°C were analyzed across southern and lower California while the -60°C isotherm continued from eastern New Mexico eastward across the southern states. The strong confluent zone was across northern New Mexico, the Texas Panhandle, and northern Oklahoma. Strong warm advection outside the confluent zone was occurring across northern Mexico into southeastern New Mexico and was forecast to continue eastward across North Texas. The 700mb temperature 8° lat upstream was 5C° warmer than that observed over North Texas. The snow index was therefore computed as 10 degrees warm advection at 200mb, divided by 2 to equal 5 (inches of snowfall). Observations and thickness forecasts indicated the snow would be north of the 200 contour on the 200mb chart. Radar detected scattered light rain over extreme West Texas beginning at 05GMT. It spread rapidly eastward to near Abilene, falling as freezing rain, by 10GMT. Precipitation changed to snow within a few hours.

By 12GMT January 30 (Figure 7), the strongest indicated warm advection at 200mb was 17C° over northeast Texas. Warm advection was continuing at 700mb, the index became 8-1/2 inches. The strong confluent zone continued over northern Oklahoma and, to a lesser extent, over northern Arkansas. The first indication of a surface low was a reported 1017mb pressure near Brownsville, 330nmi south of the snow falling at Fort Worth at the time. By 12GMT January 31, significant snowfall was recorded over the area indicated by the dash-dot line in Figure 7. A maximum of 8 inches was reported at the point indicated by the "8" while 6-inch accumulations were reported where indicated by the two "6"s. Slightly more than one inch fell at Abilene where the snow ended about 2240GMT on the 30th. Three inches was reported at Jackson, MS, where the snow ended about 0920Z on the 31st.

The 00GMT January 31 200mb chart is shown in Figure 8, about 9 hours before the snow ended at Jackson.

If the 200mb charts had been used to forecast the snow amount, the 00GMT January 30 chart would have produced a reasonable forecast. The 12GMT January 30 chart would have overforecast the amount.

SUMMARY

1. The average snowfall in the ensuing 24 hours, in inches, will be about 1/2 the indicated warm advection in C degrees at 200mb, provided warm advection is occurring at 700mb. If cold advection is occurring at 700mb, then the snowfall will be approximately 1/4 the 200mb advection term. Neutral advection is treated as warm. Limit the 200mb advection to about 840nmi, or 14° lat, upstream for a 24-hour forecast (21° lat for a 36-hour forecast).

2. Limit the use of this forecast technique to the period of mid-October to March 10.

3. Little or no precipitation occurs in areas of strong confluence at 200mb.

4. This technique is intended as a supplement to, not a substitute for, established forecast practices.

ACKNOWLEDGEMENTS

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TABLE I

Date	Index	Average Snowfall	Observed Maximum Snowfall	Location
10-18-76	2	2	2	ERN SD-MN
10-20-76	2	2	4	SRN QUE
10-21-76	2.5	2	4	SRN QUE
10-22-76	2.5	2	4	MT
10-23-76	1	2	2	ERN SD-MN
10-26-76	2.5	4	8	ERN CO-WRN KS
10-31-76	5	5	11	SERN QUE
10-31-76	4.5	5	5	VT-NH
11-3-76	3	1	1	NH
11-5-76	6	2	5	NY-NH
11-6-76	1.5	2	2	LWR MI
11-11-76	0	2	5	KY-WV
11-12-76	4	4	6	SERN NM-WRN TX
11-13-76	8	4	10	N CNTRL TX
11-13-76	3	3	5	NWRN AR
11-14-76	3	2	3	WV
11-15-76	1.5	0	0	CT
11-18-76	1.5	3	4	SRN ONT
11-19-76	1	1	1	NY-MA
11-24-76	2	1	1	NERN MT
11-25-76	3	2	5	MT-WY
11-26-76	3	2	5	WRN KS
11-27-76	2.5	3	6	NM
11-28-76	2.5	2	5	SRN IL-NH
11-29-76	1	1	2	NY-ME
11-29-76	0	1	3	WRN ND
12-1-76	5.5	0	0	NY-NH Snow at Buffalo
12-4-76	2	1	3	WY
12-5-76	4	3	4	SRN MN
12-6-76	2.5	2.5	4	NE MO-SRN LWR MI
12-6-76	4	2	2	LWR MI-SERN ONT
12-7-76	2.5	1	3	ND
12-7-76	NEG	1	1	SERN SD-NERN MO
12-8-76	1.5	1	2	ND
12-8-76	1.5	1	3	NY-VT
12-11-76	1.5	0	0	VT
12-16-76	2	1	3	NE OF ME
12-20-76	3	2	2	NY-NH
12-25-76	4	3	4	WV-RI
12-26-76	3.5	6	8	ME
12-27-76	2	2	3	MN-MI
12-28-76	1.5	2	4	KY

Date	Index	Average Snowfall	Observed Maximum Snowfall	Location
1-1-77	3	1	3	TX PNHDL-SRN KS
1-2-77	2.5	2	3	SRN MO-WRN KY
1-2-77	3.5	3	5	OR-ID
1-3-77	4	3	5	NV
1-3-77	2.5	3	6	WY
1-4-77	6.5	4	6	NRN MO
1-4-77	4	4	6	WV
1-7-77	3	6	8	MA-ME
1-8-77	1.5	3	5	TX PNHDL
1-9-77	4	7	13	ERN OK-SRN MO-NRN AR
1-9-77	5	5	7	IL-OH
1-11-77	2.5	2	4	ID PNHDL
1-12-77	NEG	1	2	MO
1-13-77	3	2.5	3	IN-OH
1-14-77	3	3	4	PA
1-15-77	NEG	1	1	ERN MO-IL
1-17-77	1	1	2	MS
1-18-77	0	1	2	AL-GA
1-18-77	NEG	1	2	SERN ND-NWRN IA
1-19-77	2.5	1	3	NRN IL
1-20-77	NEG	1	2	KY
1-22-77	5	2	4	NERN KS
1-23-77	3	2	3	MO-KY
1-24-77	2.5	2	2	NY
1-25-77	2.5	3	5	ME
1-28-77	3	2	4	PA-NH
1-30-77	5	4	8	N CNTRL TX
1-30-77	8.5	5	6	NERN TX-SWRN AR
2-2-77	2.5	1	1	TX PNHDL
2-3-77	2.5	1	3	VT-ME
2-13-77	3.5	3	4	ME
2-19-77	1.5	2	4	KY-WV
2-20-77	6	5	7	MA-NH
2-22-77	2.5	3	5	WY-SWRN SD
2-23-77	7.5	6	9	ERN SD-MN
2-25-77	2	2	4	TX PNHDL
2-26-77	1.5	2	5	SERN KS-LWR MI
2-27-77	2	2	4	LWR MI

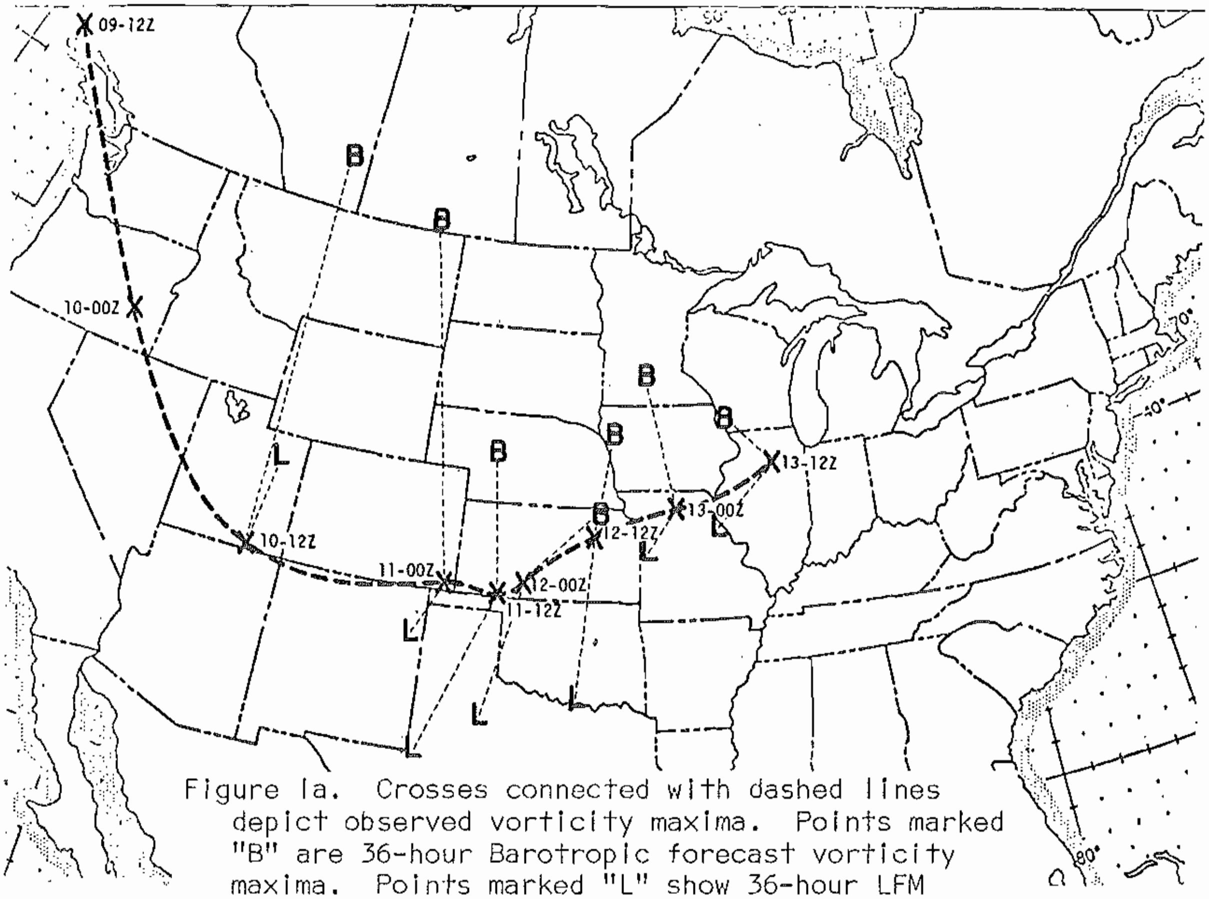

Figure 1a. Crosses connected with dashed lines depict observed vorticity maxima. Points marked "B" are 36-hour Barotropic forecast vorticity maxima. Points marked "L" show 36-hour LFM forecast vorticity maxima. Dotted lines connect the "Bs" and "Ls" to the subsequently observed position of the vorticity maxima.

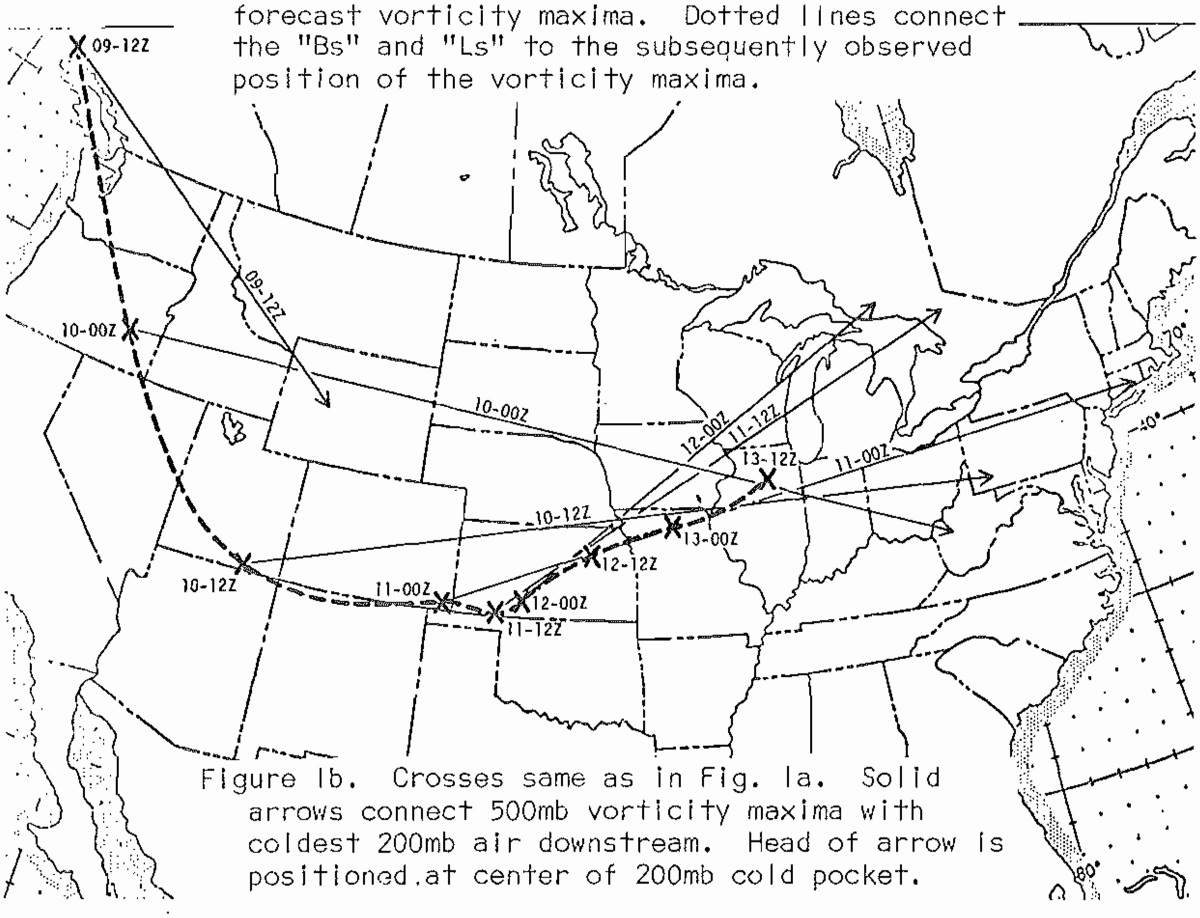

Figure 1b. Crosses same as in Fig. 1a. Solid arrows connect 500mb vorticity maxima with coldest 200mb air downstream. Head of arrow is positioned at center of 200mb cold pocket.

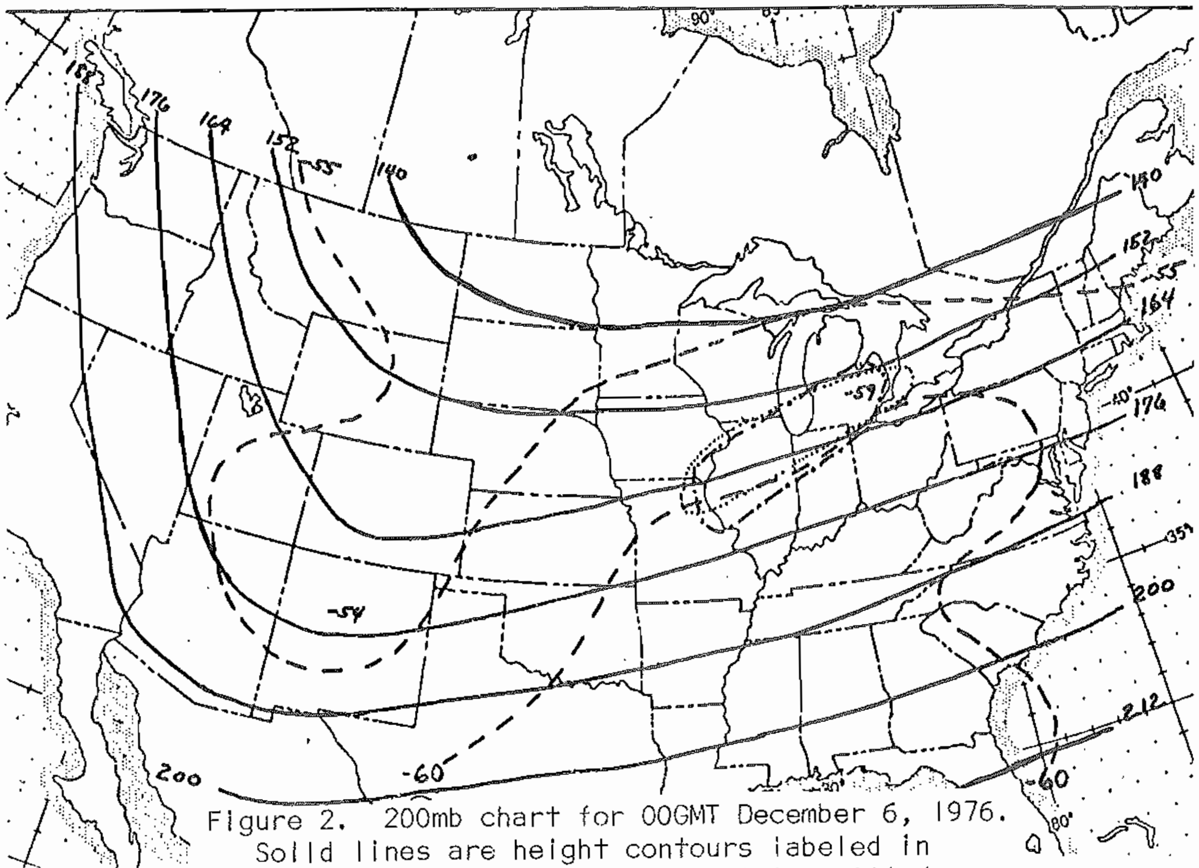

Figure 2. 200mb chart for 00GMT December 6, 1976. Solid lines are height contours labeled in decameters with the thousand digit omitted. Dashed lines are isotherms in degrees Celsius.

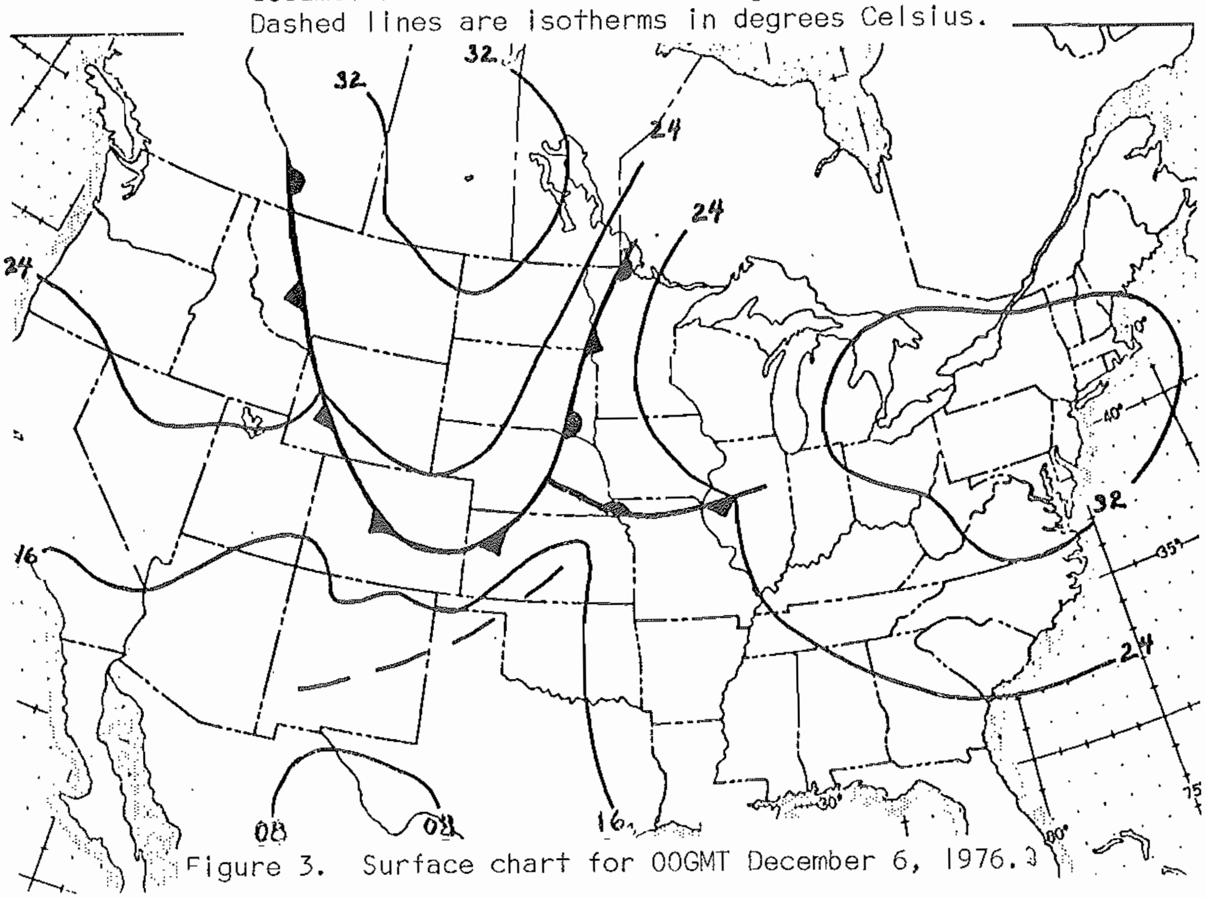

Figure 3. Surface chart for 00GMT December 6, 1976.

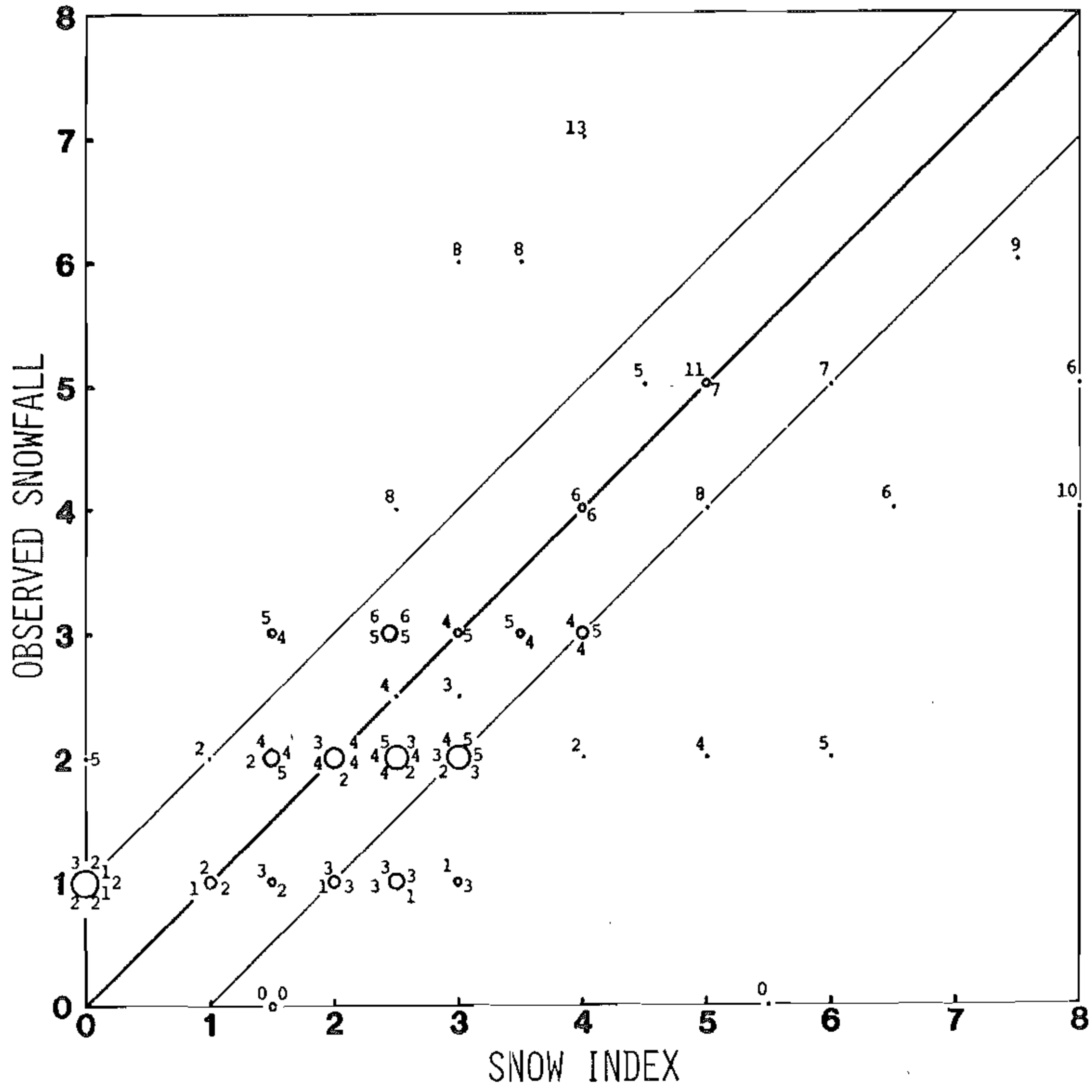

Figure 4. Graph of snow index vs. snowfall. Abscissa is snow index, or forecast snowfall in inches; ordinate is observed average snowfall in 24 hours. Plotted points sized proportional to number of cases. Numbers plotted for each point represent reported maxima.

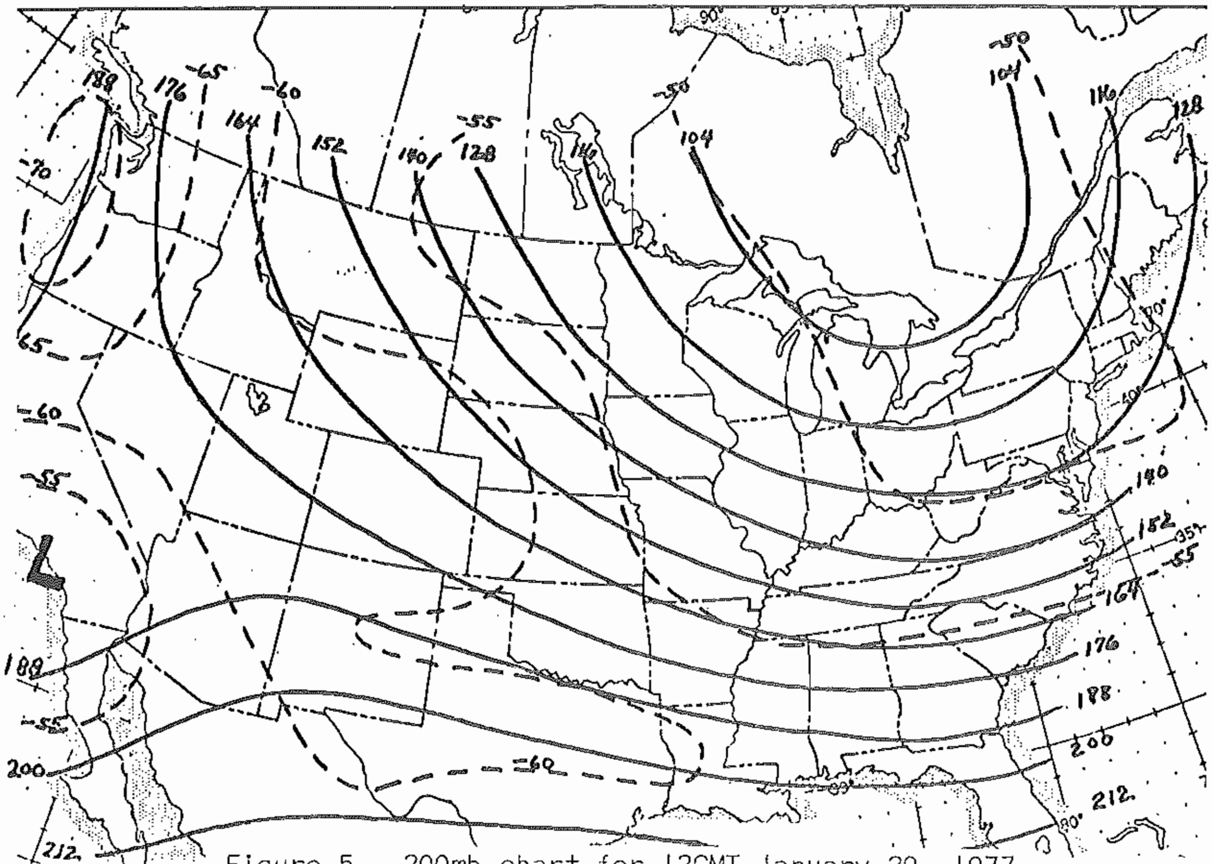

Figure 5. 200mb chart for 12GMT January 29, 1977.

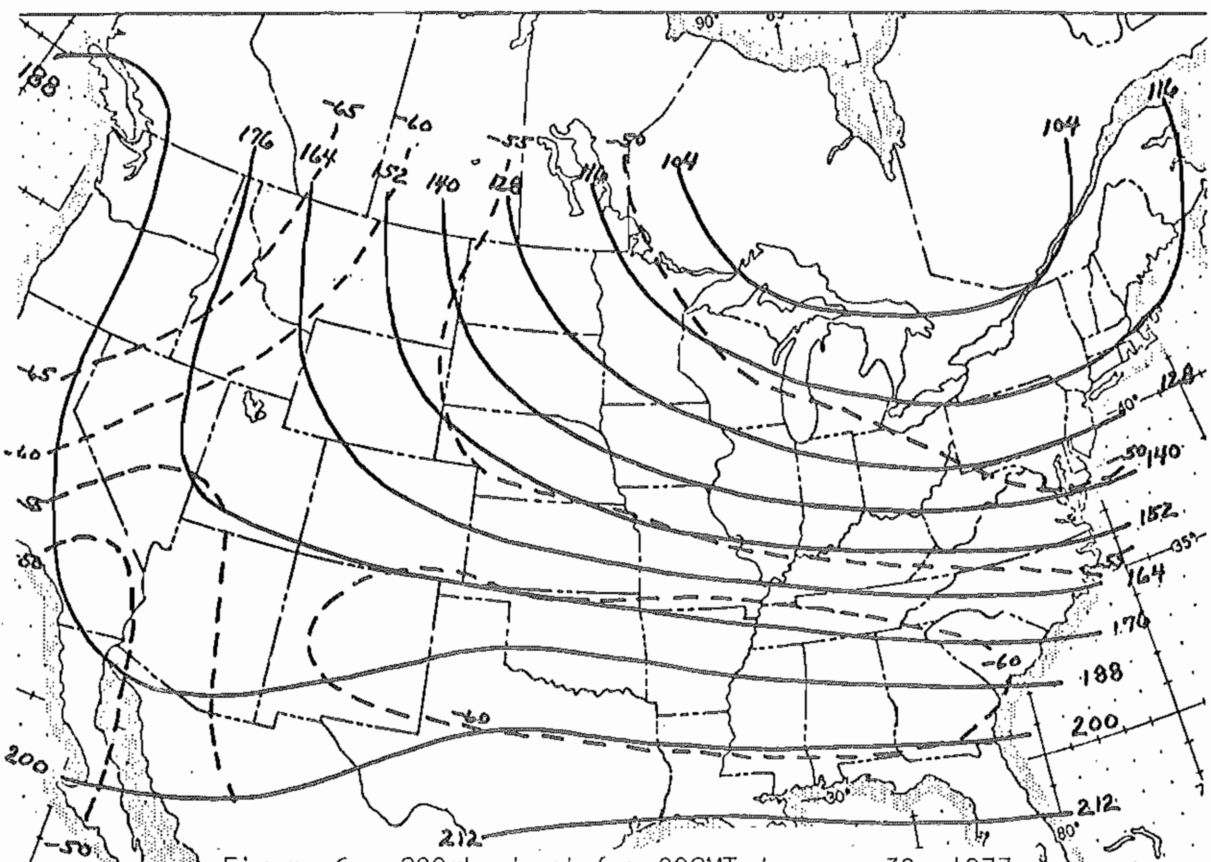

Figure 6. 200mb chart for 00GMT January 30, 1977.

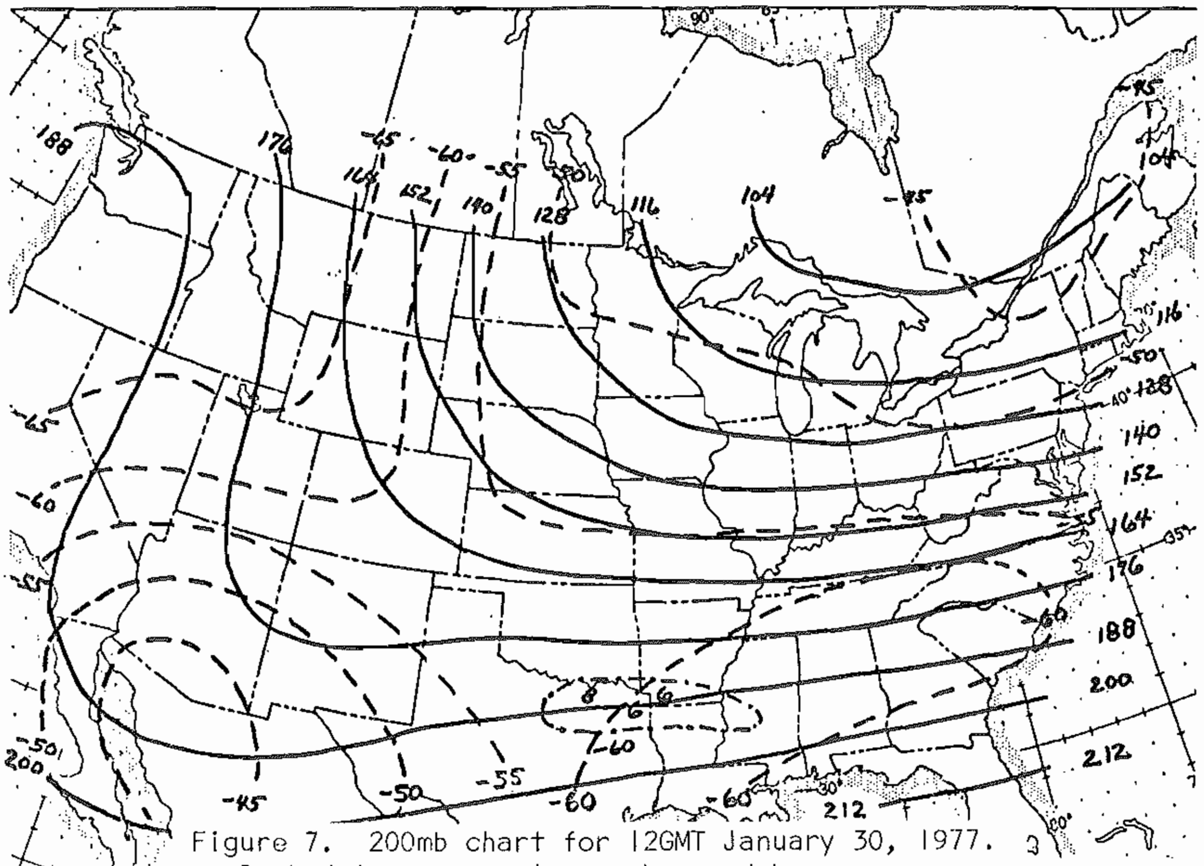

Figure 7. 200mb chart for 12GMT January 30, 1977. Dash-dot curve encloses observed heavy snow area for 24-hour period ending at chart time.

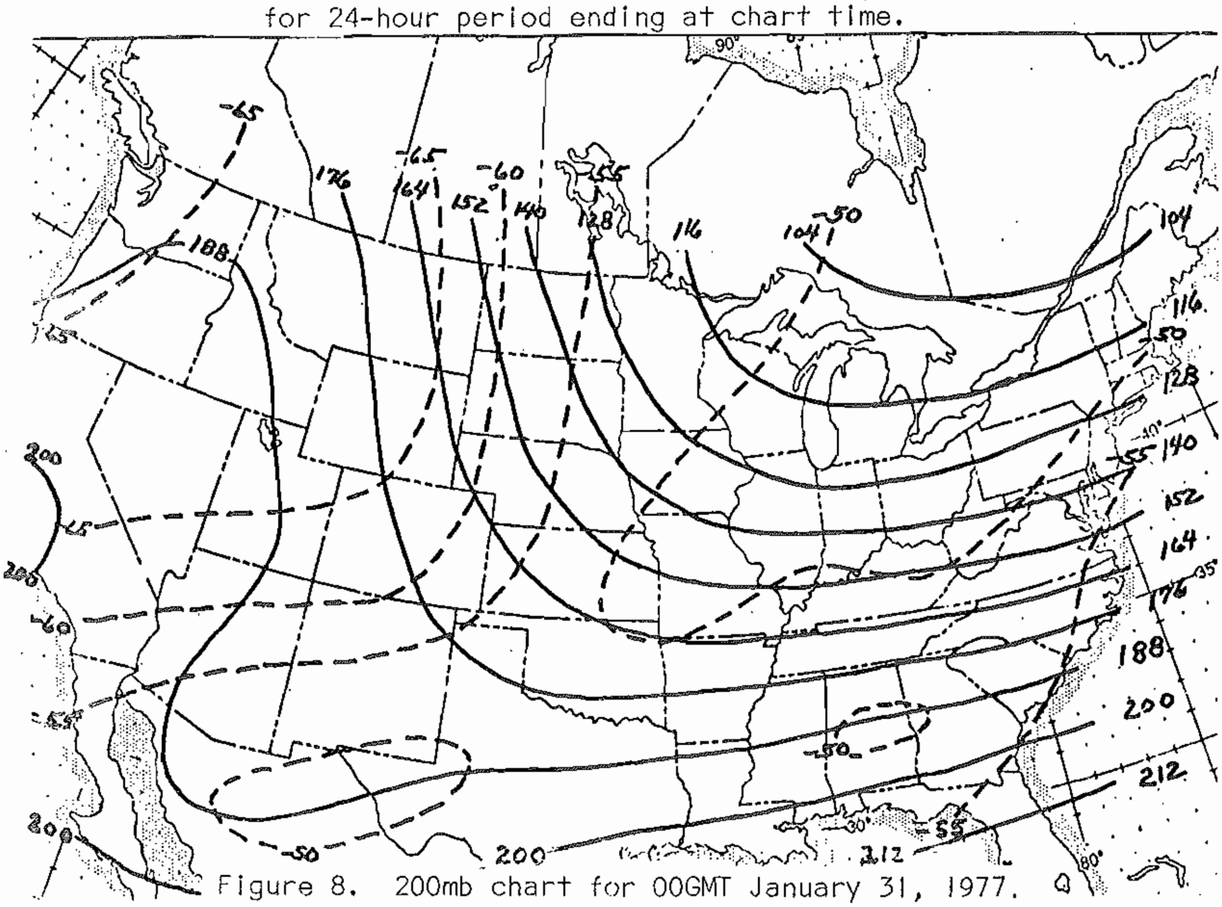

Figure 8. 200mb chart for 00GMT January 31, 1977.